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XXI.

EXPERIMENTS AND OBSERVATIONS ON THE SUMMER VENTILATION AND COOLING OF HOSPITALS.

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IN this climate, the sick in our hospitals often suffer much distress from the excessive heats of summer. Their relief demands more serious attention than it has generally received.

At first sight it would seem a simple matter by means of the cooling processes known to the arts to surround a sick bed with a cool atmosphere; but this atmosphere must be constantly renewed and the incoming air as constantly cooled; this cooling is a difficult problem, and has not been satisfactorily solved by any of these processes. It is much easier to warm our patients in winter than to cool them in summer.

The three principal ways in which our bodies lose heat are by convection, radiation, and evaporation; but they are efficient in very different degrees.

Radiation, although effective in the open air with a clear sky, does us but little good as a cooling agent on a warm and muggy day. In our wards, when their walls are near the temperature of our patients, or rather of their clothing, which is really the radiating surface, radiation benefits them but little, for these walls of necessity return nearly as much heat as is radiated to them. Neither is radiation sensibly modified by any movement of the surrounding air.

Convection, as the name implies, is the carrying away of heat; it increases inversely as the temperature of the surrounding air, and directly with its moisture and velocity. We know well the agreeable sensations on a hot summer's day of the sea breeze, which in a greater or less degree combines these qualities. We know too how much, on a still, hot day, fanning, which changes neither the moisture nor the temperature of the air, but simply causes more air to move over and come in contact with us, adds to our comfort by displacing the hot and moist air immediately around us.

The Cambridge Hospital is warmed by air heated in passing over pipes in which hot water circulates, enclosed in heating boxes; it is obvious that the substitution of cold water for hot water in these pipes would cool, more or less, the air on its way to the wards.

It was thought worth while to determine by experiment what influence this previous cooling might have on the comfort of our patients as compared with air of the same velocity from the open, unchanged in temperature or moisture.

An *air-chamber* extends under the whole ward; it is devoted exclusively to the purpose of receiving the air for ventilation and distributing it equally through the heating boxes and ten registers to the ward above. This air-chamber is well lighted, and is kept scrupulously clean; nothing is allowed to be placed in it under any pretence whatever. It is generally cooler in the summer than the atmosphere; water from the city water service is also cooler by several degrees, in the early summer, than the air. By connecting the city main with the pipes in the heating boxes, and allowing the water flowing through them to run to waste, they become in some degree air-coolers.

On the 21st of May, 1893, all windows and openings in the air-chamber were carefully closed, and the water from the main let on. At 3 P. M. the external thermometer was at 84° F.; there was no wind, and the patients were suffering from the heat. The temperature of the air-chamber was 67° F.; the water as it entered the cooling boxes, 57–58°. The electric fan, 36 inches in diameter, driving the air into the air-chamber, was put in motion, making 500 revolutions with an air-moving power of 10,200 cubic feet a minute. At 4 P. M. the air entering the ward at the registers was at 71° F.

During this hour 400,000 cubic feet of air, as measured by a Casella's air-meter, was thrown into the ward through the ten registers; a quantity sufficient to fill the ward of 21,000 cubic feet twenty times an hour, — once in three minutes.

The result was satisfactory; the comfort of the patients was manifestly improved.

But it must be observed that the cooling surfaces were, first, the ten cooling boxes of 30 square feet each at 57–58° F., and, secondly, the floor and walls of the air-chamber, the two together amounting to about 3,300 square feet. The temperature of these walls could not well be determined; but as they had not been exposed to much increase of heat since the winter, they may be assumed to have been about that of the water supply, then 58° (in winter it is about 50°). At the outset then we had the air-chamber full of cool air and a cooling surface

of about 3,000 feet along which the air, driven by the fan, was diffused before it entered the ward. The cooling power of the boxes may be assumed to be about one tenth that of the walls.

These were the arrangements through the month of May, with the same benefit to the patients. In June, the summer heats were greater and more constant, and the fan more steadily used. The temperature of the air-chamber and the air passing through it had increased, and that of the water had already risen to 70°, and is usually somewhat higher later in the season; the quantity of water required was large and expensive; it was therefore shut off permanently. The same amount of ventilation, however, was continued, and the conditions as to the air-chamber and the admission of the air to the ward were unchanged. During the summer, the ward temperature gradually rose until it differed but little from that of the open air.

Still the comfort given to our patients and their nurses under both these methods was immediate and decided. To those entering the ward there was a feeling of freshness and freedom of air quite beyond that of the other ward of similar construction, which had only the usual summer ventilation.

At first the walls of the air-chamber to a degree acted as coolers, but this ceased as they became warmer.

We may form some estimate of the probable effect of the boxes as coolers in summer, by comparing it with their work as heaters in winter.

The average boiler temperature in December and January is 200° F.; that of the return, 145°; therefore, 55° of heat is lost in heating 120,000 c.f. of air hourly supplied to the wards in winter.

From these data Professor Trowbridge has kindly made the following computation: —

"Mean temperature of water	$= 172.5°$	(173°)
" " " air	$= \frac{1}{2}(30 + 70) =$	50
Mean excess of water temperature available	$173-50 =$	123
Excess per degree rise of air temperature	$\frac{123}{40} =$	3.07

"To cool the same amount of air from 80° to 70° (mean temperature 75°) would require, if Newton's law hold, a mean temperature of $75° - 10 \times 3.07 = 45°$ approximately."

Our boxes, therefore, as then constructed, with a water circulation at 58° F., were inadequate to our purpose as cooling boxes. It is true the boxes could be enlarged. It has been computed that, with a constant flow of cool water at 50° through boxes 5.6 times as large

as those we now have, we might keep a ward at 70° with an outside air of 90°, and a ventilation reduced to 40,000 cubic feet an hour, — one third of our winter supply, or one tenth of our summer supply. But we have no rĕliable experiments to confirm this computation. Our own experiments have shown that this previous cooling of the air is an expensive and uncertain process, and would lessen the evaporation upon which, as we shall see further on, we principally depend for cooling, and, what is more important, would probably not be hygienic. No further experiments were made as to cooling the air before its entrance into the ward.

Our first experiment showed clearly enough the advantage of a large supply of fresh and slightly cooled air; but it is not so clear how much was due to the temperature of the air, and how much to the rapid evaporation caused by its velocity and dryness. But as the comfort of the sick continued the same after the rise of temperature of the cooling apparatus and the shutting off of the cold water, it is probable that it was due more to the velocity and drying qualities of the air acting upon the *patients themselves*, than to any change of temperature in the ward generally, which, as we have already said, differed but little from that of the open air. This is a point of the first importance.

The most effective way of losing heat is that last mentioned, that is, by evaporation. It is Nature's great consumer of heat. Evaporation increases with the temperature of the air, with its dryness, and with its velocity. Common observation teaches how rapidly wet clothing and muddy roads dry in windy weather. If we are exposed to a warm dry air, especially if it is in motion, we may feel cool, or even cold, because of the rapid evaporation from the skin. In the heats of summer the relative dryness of the air is of more importance to our comfort than its temperature. The thermometer and our sensations do not correspond. It is evaporation increased by the air put in motion by his punkah that enables the Englishman to bear the heats of India and keep his blood at its normal temperature.

Pettenkofer calculates that in twenty-four hours we lose heat, by respiration alone, as follows: —

In dry air at 32° F.	293,044	units	of heat.
" " 86°	274,050	"	"
A difference of about	19,000	"	"
In air completely humid at 32°	265,050	"	"
" " " " 86°	105,390	"	"
A difference of nearly	160,000	"	"

The cooling by respiration in moist air is therefore about one eighth of that in dry air at the same temperature. But this is not all the heat lost by evaporation, nor the greater part; the loss by the skin is nearly twice that by the lungs under the same conditions. Here also the same law holds, the greater the relative moisture the less evaporation and consequently the less cooling.

According to Lavoisier and Seguin, 900 grams of fluid per day are discharged by perspiration, and 500 grams from the lungs, making 1400 grams of fluid lost in twenty-four hours. The evaporation of this quantity of water will consume 750 units of heat, or about one fifth of all the heat produced in the body in twenty-four hours.

The production of heat in the animal body, and its maintenance at a normal standard, are two of the most important processes in the living organism. The two chief means for regulating the temperature of the body are the skin and the lungs. Of these the most direct and simplest is that by the cutaneous perspiration. The relations of these organs to the atmosphere, therefore, are of great importance in the question now under consideration.

But the rate of evaporation and consequent cooling depends in great measure on the aqueous vapor already in the atmosphere. That this relative amount has a material influence on our individual comfort there is no doubt. It is certain that on those days when the proportion of humidity is greatest, even the healthiest feel an oppression and languor, and that on other days when the humidity is less there is an exhilaration of spirits and an increase of muscular energy.

It is worth while, then, to recall the laws governing this aqueous vapor, for it pervades the atmosphere, is one of the main causes of its movements, and the only fluctuating ingredient in its composition.

The evaporating power of air raised to a higher temperature is increased. A quantity of air absolutely humid at 59° F. holds an amount of vapor equal to $\frac{1}{80}$ of its weight; at 86°, $\frac{1}{40}$; at 113°, $\frac{1}{20}$; at 140°, $\frac{1}{10}$; so that while the temperature advances in an arithmetical progression, the vapor-diffusing power of the atmosphere rises with the accelerating rapidity of a geometrical series having a ratio of two; with the same ratio, evaporation increases, and consequently the cooling process.

It is upon this play of forces in the aqueous vapor and the air, and the movements they bring about, that we must rely for the comfort of our patients in the heats of summer. It is not a question of changing the temperature of the air; practically, we cannot alter that nor its

humidity, in the volumes required for ventilation. It is a question of the rate of evaporation from a perspiring surface, which again is governed in great measure by the velocity of the air; and this by the improvements in the arts we can control.

If, on the other hand, we attempt to attain our object by cooling the air before it enters the ward, we are met with this fact. If air absolutely humid comes in contact with warmer air also saturated, the latter will be cooled, it will approach the dew-point, and, if its moisture is condensed into visible vapor, will give out heat. Evaporation consumes heat, condensation liberates heat.

In our first experiment the previous cooling of the air did not bring it to the point of condensation, but its relative humidity was increased; the rate of evaporation was therefore diminished, and to that degree it was a disadvantage.

The quantity of air required for our purpose cannot, as we have already said, be determined by instruments of precision alone; it must be learned by experiment and the declared sensations of the sick.

The movement of the air around us, and it is never still, — the natural ventilation as it is called, — is much greater than is generally supposed. Repeated experiments have shown that at two feet a second we first feel the air as a moving body; less than that we consider a perfect calm. And yet at this velocity air would move from end to end of our ward of 60 feet in 30 seconds, and across it in half that time, quite unnoticed by us.

To give comfort during the excessive heats of summer the sick require three or four times the air needed for satisfactory ventilation in winter. It required 400,000 cubic feet an hour for our sixteen patients, and yet while this large quantity was passing through the ward it was only known, except at the registers, by the accompanying sense of freshness and pleasant coolness; it was never felt as a draught.

"The great regulator of the heat of the body is undoubtedly the skin." Physiology teaches that perspiration is a secretion, in a sensible or insensible form, constantly going on. Increased heat increases perspiration, and the evaporation of this increased quantity consumes in work a large portion of the heat derived from the atmosphere, and thus prevents an undue rise of the temperature of the bodily organs. The very intensity, therefore, of the peripheral circulation, under the action of heat, leads the way to relief.

Experiments made more than a hundred years ago prove that, if the skin perspires freely and the perspiration be readily evaporated,

the temperature of the body may remain nearly normal in an excessively hot atmosphere, — even more than 200° F.

In the present atmosphere of mixed air and aqueous vapor, with which it is never saturated, evaporation and convection must coexist. So long as the expired air is loaded with moisture, and the skin performs its perspiratory function, and the movement of the surrounding air is under our own control, if, so to speak, we own a breeze, we may confidently rely on our ability to dispense its comforting and refreshing influences to the patients in our hospital.

The following observations with the wet and dry bulb thermometer may serve to illustrate the cooling of a moist surface. June 17, 1894, a thermometer in a still room was at 78° F.; after covering the bulb with a piece of thin cotton cloth moistened with water, and fanning it for five minutes with a common fan, it fell to 72°, — a difference of 6°. The same thermometer on the same day at 99°, treated in the same way, fell to 77°, — a difference of 12°. A thermometer in the open air in the shade, July 13, 1894, with a gentle breeze, was at 95°; with a moistened bulb, at 73°, — a difference of 12°. The relative humidity at the same time was 53%.

But the air must be in motion. A perspiring patient in still air is surrounded by an atmosphere permeated by much aqueous vapor; this must be diffused and carried away from the neighborhood by the continued arrival of fresh drier air, to get the full cooling effect due to evaporation.

It is in this way that simple agitation of the air in a warm still room brings relief, as with a common fan, or the rotary fan of the shops, or the Indian punkah. So it is with a ride in the open electric car on a hot day; the relief is immediate. There is no atmospheric change either in temperature or in moisture; it makes no difference whether we move through the air, or the air moves by us, the sense of cooling is the same. In both, we are surrounded by air constantly renewed, bringing with it the pleasurable sensations and invigorating influences belonging to a freely moving atmosphere.

What these influences are to those in health we know; what they are to those languishing on beds of sickness, those only who have experienced them can fully appreciate. That the patients in our hospital have derived much comfort from them, their repeated declarations fully prove. Besides the physical comfort they give, — like the suggestions of flowers and music, with which the sufferings of the sick are now so often soothed, — these large volumes of air fresh from the fields seem to hold up to the mind of the convalescents suggestions of other

scenes, which displace, for the time at least, present surroundings, and encourage the hope, so helpful to the sick, of a speedy return to their former enjoyments.

The experience of the Cambridge Hospital leads to these two conclusions: first, that fresh air directly from the open, in the quantity and manner there supplied, can be made to give great comfort to the sick during the heats of summer; and, secondly, that previous cooling of the air so supplied is difficult and practically useless.

To this may be added, what is of much importance to charity hospitals, that the method here adopted is the least expensive of the cooling processes hitherto made generally known.